NHDES-R-WD-19-03

Extending the Daily Streamflow Period-of-Record at the USGS Gage Site on the Cold River and the USGS Gage Site on the Warner River

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1. Introduction and Overview

New Hampshire Department of Environmental Services (NHDES) is responsible for developing and applying the Instream Flow Rules to Designated River basins. NHDES has developed rules in accordance with RSA 483 that describe how protected instream flows (PIFs) will be determined and implemented on the designated rivers. With the assistance of its advisory committees, NHDES determined that the next two river basins to be assessed for the development of watershed-specific PIFs are the Cold River and the Warner River watersheds. In preparation, NHDES asked HYSR to extend the period-of-record at these gages using its QPPQ Transform method.

HYSR demonstrated the QPPQ Transform method in two earlier studies for NHDES. In the first study a key aspect of the QPPQ Transform method was updated, namely a mathematical regional streamflow duration (FDC) model (see Fennessey, 2018a). The second study (Fennessey, 2018b) focused on a special time-series analysis designed to compare daily QPPQ Transform flows with USGS gaged flows at the same location during the summer and early fall. These studies demonstrated that the QPPQ Transform is well suited for developing protected instream flows for ungaged designated rivers and reaches.

In this study, the QPPQ Transform method is used to extend the period-of-record of daily flows at two USGS streamgage sites: one on the Cold River at Alstead and the second on the Warner River at Davisville. The Cold River at Alstead gage record is short and begins September, 2009. The Warner River at Davisville gage records began in 1940 and ends in 1978 and then begins again in September 2001. With this extension, the daily streamflow time series at both sites is continuous from October 1, 1950 through September 30, 2017.

The focus of this report is an assessment of how well the method worked by analyzing concurrent observed daily flow and QPPQ Transform estimated daily flow at each site. A complete record using the QPPQ Transform method was developed from October 1, 1950 through September 30, 2017 HYSR conducted assessments comparing the daily stream flows during the most flow-sensitive time of the year. Streamflow records from the QPPQ Transform method and those measured at USGS gages were compared for the years with concurrent flow records. The results demonstrate that the flow records from the QPPQ Transform method compare well with the observed data during the most flow-sensitive time of the year and are appropriate for use as daily stream flows for these rivers.

2. Using the QPPQ Transform to Extend Daily Streamflow Gage Records

In the previous two studies for NHDES, Fennessey (2018a, 2018b) described the QPPQ Transform method in detail and demonstrated its application and fitness at five USGS streamgage sites located in New Hampshire. In both studies, QPPQ Transform daily streamflow time series at each test streamgage site was computed and compared with the observed historic streamflow at that site. These studies were tests and so the observed streamflows at these sites were not used to develop the daily time series while testing the QPPQ Transform method.

When used to estimate daily flows at an ungaged site, a FDC is constructed using GIS-based, watershed specific climate, soil and topography factors.[1] The FDC describes the range and frequency of daily streamflows. Development of the FDC is a key step towards estimating daily streamflows in the QPPQ Transform method. Because observed historic streamflow records exist at both the Cold River and Warner River USGS gage sites, for the present study it is not necessary to use the GIS-based watershed factors to construct a FDC. Instead, a FDC was developed directly from the historic daily flows available from the historical records from each stream gage site.

3. Extending the Cold River and Warner River Records

The Cold River at Drewsville, NH (01155000) was gaged by the USGS from 1940-1978. The watershed area of this site is estimated to be 82.7 mi^2. A new gage site located approximately 1.8 miles upstream from the Drewsville site was established at Alstead, NH (01154950) in 2009 and is on-line today. The watershed area of the new site is 74.6 mi^2.

HYSR extended the period-of-record (POR) of the Cold River at the Alstead site using two different methods. First, the Alstead gage record was extended to start in October 1950 and

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[1] Those watershed factors were discussed previously by Fennessey (2018a). The GIS data layers were described by Falcone et al. (2010), and were tabulated for thousands of watersheds throughout the US and compiled as GAGES-II (see Falcone, 2011).

run through September 1978 using the Cold River at Drewsville historic daily gage data and the Watershed Area Ratio (WAR) method discussed by Fennessey (2018a). Following completion of this approach, the POR of daily flows for the Alstead gage site is October 1950 - September 1978 (WAR estimated) and October 2009 – September 2017 (observed).

HYSR used the QPPQ Transform method to fill the POR gap from October 1978 through September 2009. This was accomplished by using the extended POR of 1950-1978 and the observed 2009-2017 daily data to generate the QPPQ Transform's math model parameters. The USGS gage, Smith River near Bristol, NH (01078000), was selected as the nearest-neighbor (NN) index gage from the Hydro-Climatic Data Network (HCDN), (see Slack and Landwher, 1992). The watershed area of the Smith River index gage site is estimated to be 85.8 mi^2.The QPPQ Transform method applied daily stream flows from this index gage to estimate daily flows for October 1950 – September 2017.

The final extended time series of October 1, 1950 – September 30, 2017 daily flows of the Cold River at the Alstead, NH (01154950) gage site consists of WAR estimated daily flows (October 1950 – September 1978), QPPQ Transform estimated daily flows (October 1978 – September 2009), and observed daily flows (October 2009 – September 2017). Only the daily flows for 1979-2008 from the QPPQ Transform time series are used to extend the Cold River gage records. The rest were used to assess the method, as will be discuss in Section 4 of this report.

The Warner River at Davisville, NH (01086000) was gaged by the USGS from 1940-1978, taken off-line and then put back on-line in 2002. The watershed area of this site is 146 mi^2. HYSR extended the Warner River at the Davisville site using only the QPPQ Transform method to fill in the POR gap from October 1978 through September 2001. This was accomplished using the observed Warner River daily records, in this case from October 1950 – September 1978 and October 2001 – September 2017. Again, the QPPQ Transform's math model parameters were developed from this observed daily flow data. The USGS gage, Smith River near Bristol, NH (01078000), was also selected for the Warner site as the nearest-neighbor HCDN index gage. The QPPQ Transform method applied daily stream flows from this index gage to estimate daily flows for October 1950 – September 2017.

The final extended time series of October 1, 1950 – September 30, 2017 daily flows of the Warner River at Davisville, NH (01086000) consists of observed daily flows (October 1950 – September 1978), QPPQ Transform estimated daily flows (October 1978-September 2001), and observed daily flows (October 2001 – September 2017). Only the daily flows for 1979-2001 from the QPPQ Transform time series are used to extend the Warner River gage records. The rest are used to assess the method, as discussed in Section 4 of this report.

4. Assessing the Extended Cold River and Warner River Records

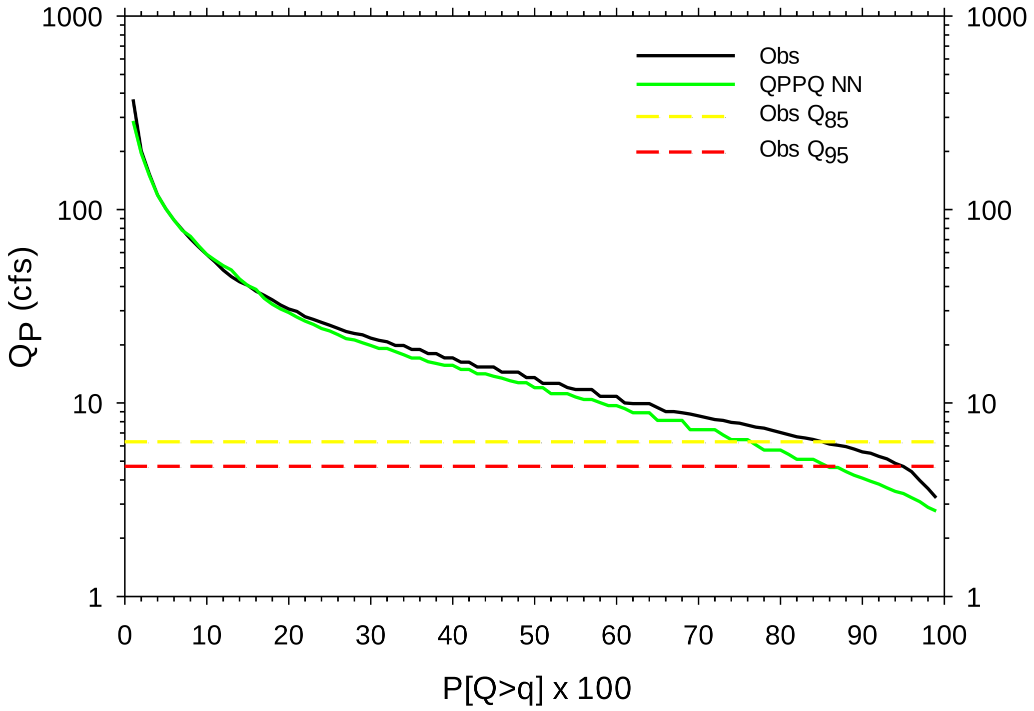
The following assessments apply to the concurrent periods of observed daily streamflow data and QPPQ data for the Cold and Warner Rivers. These assessments apply to a test season chosen to focus on the summer low flows and they apply selected flow thresholds as indicators.

Because historic gage records exist at both sites, HYSR examined and compared the observed data at each site with the concurrent QPPQ Transform nearest-neighbor HCDN site data. From above, the concurrent POR for the Cold River is October 1950 – September 1978 and October 2009 – September 2017. In this case, HYSR treats the WAR-transformed 1950-1978 flow records from the Drewsville site as observed records for the Cold River at the Alstead site. For the Warner River, the concurrent POR is October 1950 – September 1978 and October 2001 – September 2017.

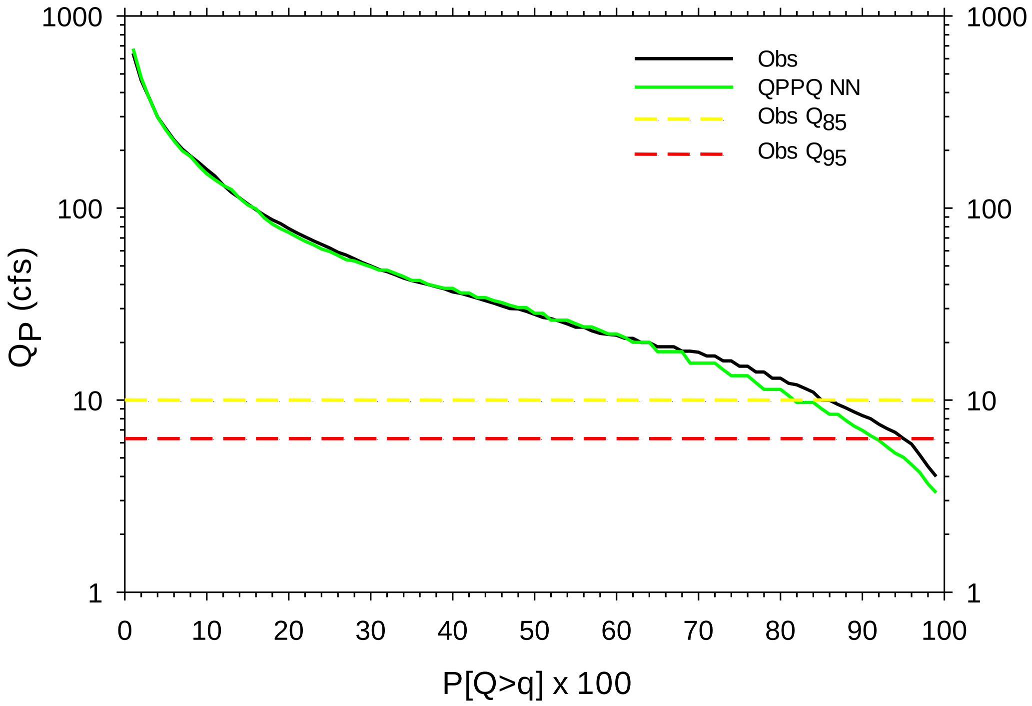
As described by Fennessey (2018a and 2018b), NHDES and HYSR both believe that the period of particular concern to fishery specialists is during summer into early fall when stream flows are typically low. Fennessey (2018a and 2018b) used the July 15 – September 30 summer flow season that was used by the University of New Hampshire et al. (2007). In those same Fennessey studies two season-specific flow rates, Q_{85} and Q_{95}, were used as assessment thresholds. For the present study, HYSR again uses this season and these flow rates to assess the effectiveness of using the QPPQ Transform to extend the Cold and Warner River gage records.

The first assessment used is the streamflow duration curve or FDC as was described by Fennessey (2018a, 2018b). As shown in Figures 4-1a and 4-1b, the observed FDC (black line) is compared with the QPPQ Transform FDC (green line) for concurrent POR summer flow seasons using the nearest-neighbor HCDN gage site to drive the process. The summer season Q_{95} and Q_{85} flow rates indicated on each graph are estimated using the concurrent observed gaged flow data.

In the case of the Cold River, the QPPQ Transform estimated flows are slightly less than the concurrent observed flows starting about Q_{20}. However, those differences converge as flows become very small starting about Q_{95}, which is when the habitat is most stressed. For the Cold River, the QPPQ Transform estimated flows are slightly less than the concurrent observed summer season flows starting about Q_{60} or so, but those differences converge as flows become very small starting about $Q_{95,}$ as was the case with the Cold River. Relative to the observed threshold management flows, Figure 4-1a indicates that the Cold River observed Q_{85} is approximately equal to the QPPQ Transform Q_{78} and the observed Q_{95} is about equal to the QPPQ Transform Q_{88}. Similarly, Figure 4-1b indicates that the Warner River observed Q_{85} is approximately equal to the QPPQ Transform Q_{82} and the observed Q_{95} is about equal to the QPPQ Transform Q_{91}. These results are quite good for the narrow window and low range of flows occurring within this season.



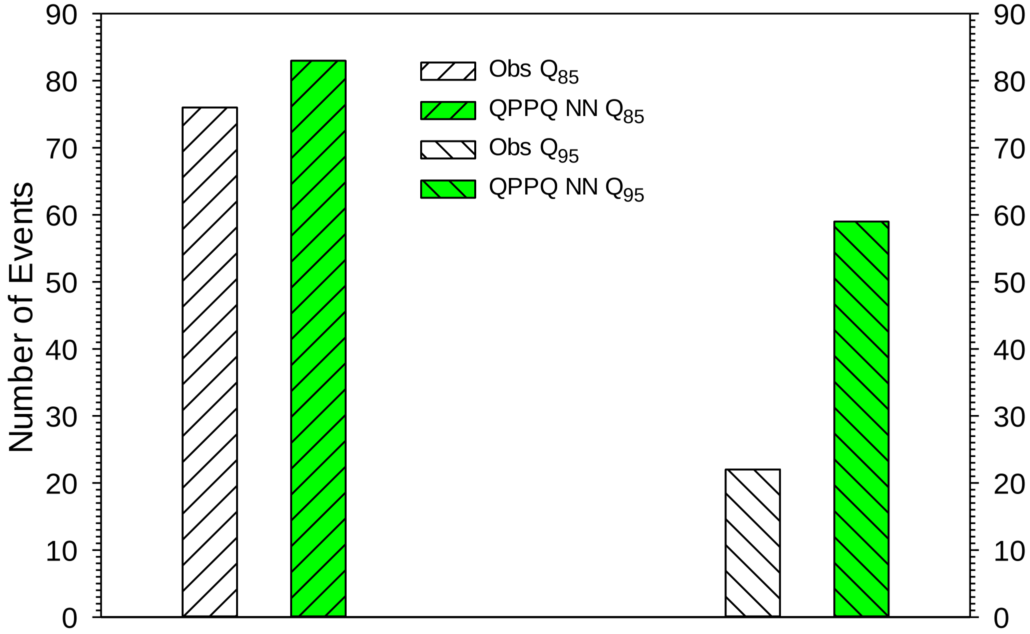
Fig, 4-1a. Cold River Summer Season FDCs



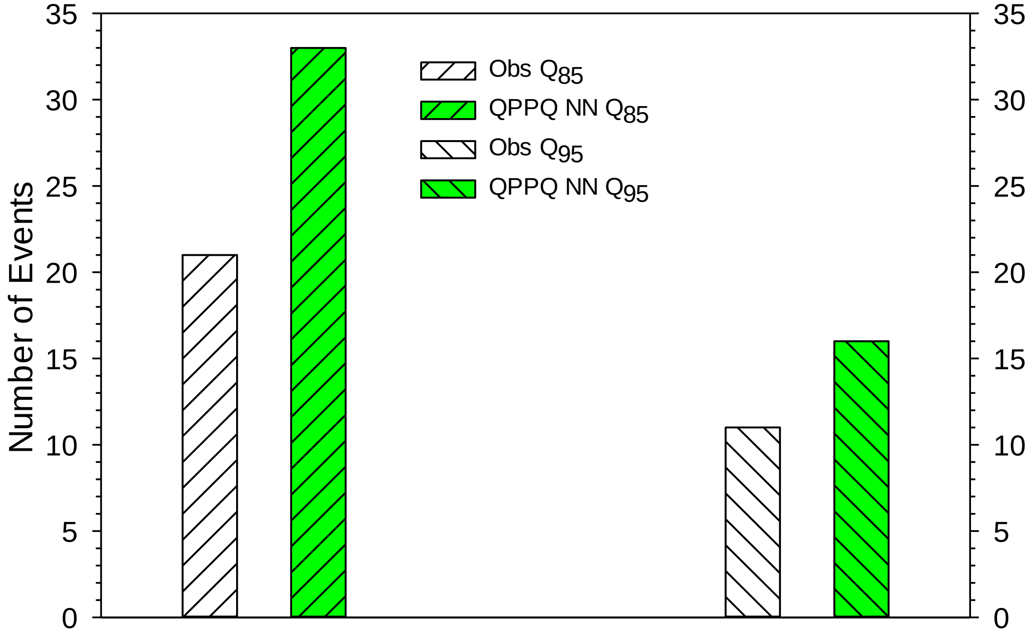
Fig, 4-1b. Warner River Summer Season FDCs

For the second assessment, HYSR undertook an extensive negative run-length analysis as described by Fennessey (2018b). In addition to summer season specific FDCs, this is another way to compare observed historic flows to QPPQ Transform estimated flows. A negative run-length event is a period of continuous days when flows fall below a threshold streamflow rate and then recover and rise above that threshold, which signals the end of the event. The two test management thresholds used are the summer season Q_{95} and Q_{85} gaged flow rates estimated using the concurrent observed flows for this analysis.

Figures 4-2a and 4-2b below illustrate the first negative run-length event assessment. These results show the difference between the total number of sub-Q_{85} and sub-Q_{95} negative run-length events that took place during the summer season for the concurrent POR of both the observed and QPPQ Transform estimated flows of the Cold River and Warner River respectively.



Fig, 4-2a. Cold River Summer Season Total Number of Negative Run-length Events



Fig, 4-2b. Warner River Summer Season Total Number of Negative Run-length Events

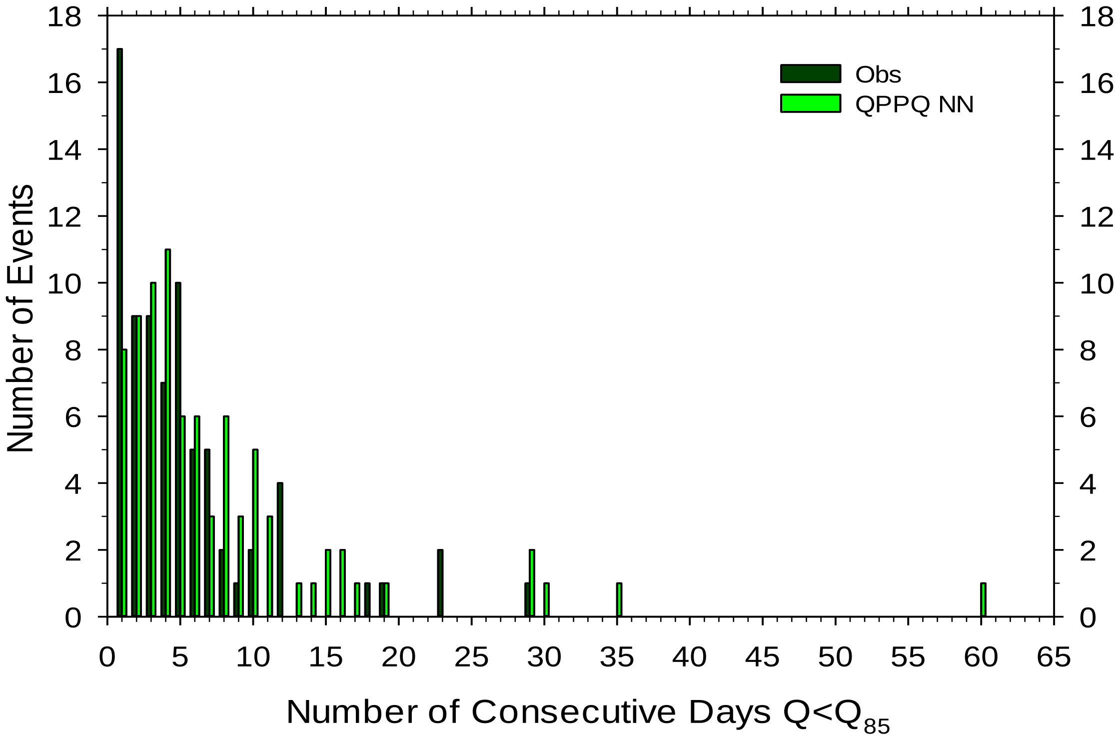
The results of this assessment are somewhat mixed. For the Cold River during the summer season, there are only a few less observed time series negative run-length events than QPPQ Transform events for the concurrent POR relative to Q_{85}; in other words, the match is quite good: 76 versus 83 events. By comparison, relative to Q_{95}, there are significantly fewer total negative run-length events and there is a greater difference between observed time series and QPPQ Transform events: 22 versus 59 events. For the Warner River, during the summer season concurrent POR there are fewer observed negative run-length events than QPPQ Transform events relative to the observed, summer season Q_{85}: 21 versus 33 events. The same is true relative to Q_{95} in that there were fewer observed negative run-length events than QPPQ Transform time series events relative to the summer season observed Q_{95}: 11 versus 16 events.

These results might be due to the observed Q_{85} and Q_{95} flow rates being greater than the QPPQ Transform time series summer season Q_{85} and Q_{95} flow rates, as discussed earlier and as shown by the FDCs of Figures 4-1a and 4-1b. Or they may partly be an artifact of parsing the frequency and durations of these events. For example, if there is one day between a pair of one-day negative run-length events, how does that compare habitat impact-wise with a single event that lasted 3 consecutive days?

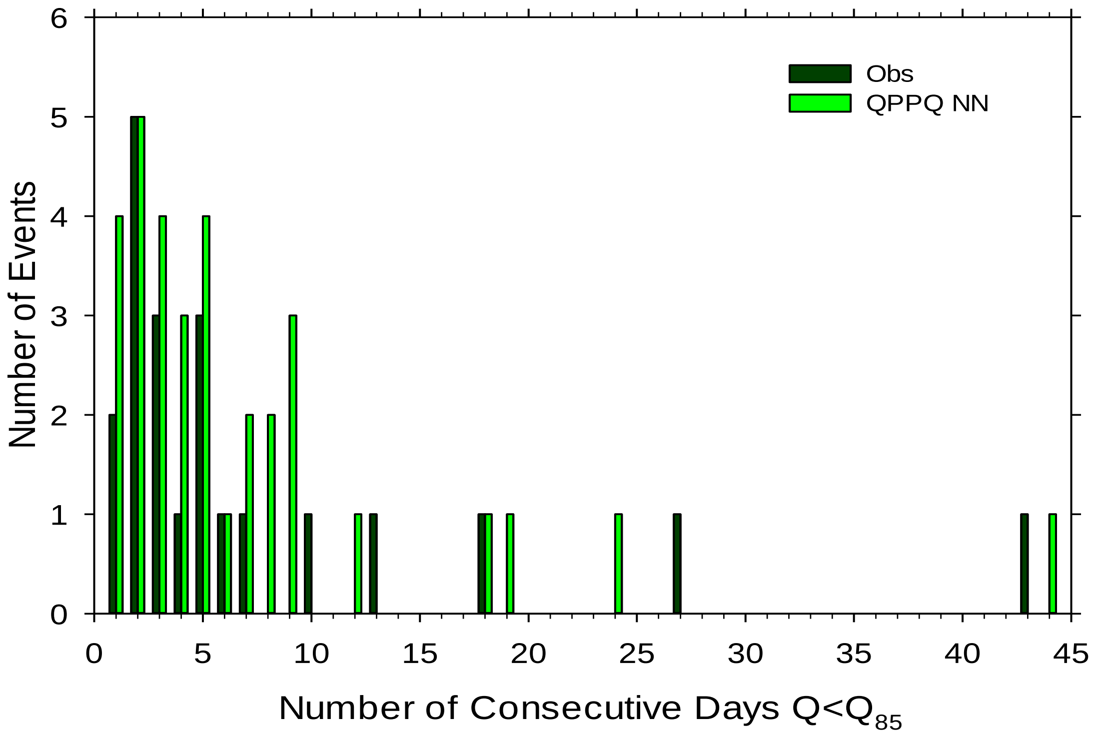
It turns out that a large portion of the differences occur during one- and two-day events where one expects the greatest variability, as described below. Note that NHDES's protected instream flow criteria for the Lamprey and Souhegan Rivers never applied durations shorter than three days to assessing negative run-length conditions. NHDES also required a two-day period of above a threshold streamflow rate before restarting a negative run-length count of days. In other words, A two-day period was the minimum duration NHDES applied to represent a recovery of stream flows (see NHDES, 2011, 2013) before the next negative run-length began. The differences between the number of shorter duration events should be given less weight.

The series of figures below illustrate the third assessment which considers the duration of the negative run-length events. These results are shown as frequency histograms which indicate the difference between the duration frequency of sub-Q_{85} and sub-Q_{95} negative run-length events that took place during the summer season for the concurrent POR of both the observed and QPPQ Transform estimated flows of the Cold River and Warner River respectively. As in the previous negative run-length assessment, each site uses the observed summer season Q_{85} and Q_{95} flow rates as test thresholds.

Figures 4-3a and 4-3b respectively show the sub-Q_{85} threshold negative run-length event duration frequency histograms for the Cold River and the Warner River. For example, Figure 4-3a indicates that there were 17 observed time series negative run-length events that lasted one day and 8 one-day events from the QPPQ Transform time series. Similarly, the longest single observed time series event lasted 24 days, whereas there were 5 QPPQ Transform time series events that lasted 23 or more days, with the single longest lasting 60 days over the concurrent POR during the 77-day-long July 15 – September 30 summer season used for the assessment. Figure 4-3a also shows that, with the exception of events that last only one day, or more than 30 days, the match is quite good, as indicated by the similar shape and clustering. Figure 4-3b indicates that the clustering of the sub-Q_{85} negative run-length events of both Warner River observed and QPPQ Transform time series is quite good. More negative run-length events do occur using the QPPQ Transform time series, which confirms the results shown on the right of Figure 4-2a, but given that both have one “extreme event” lasting about 25 days and another lasting about 43 days, the match is quite good.

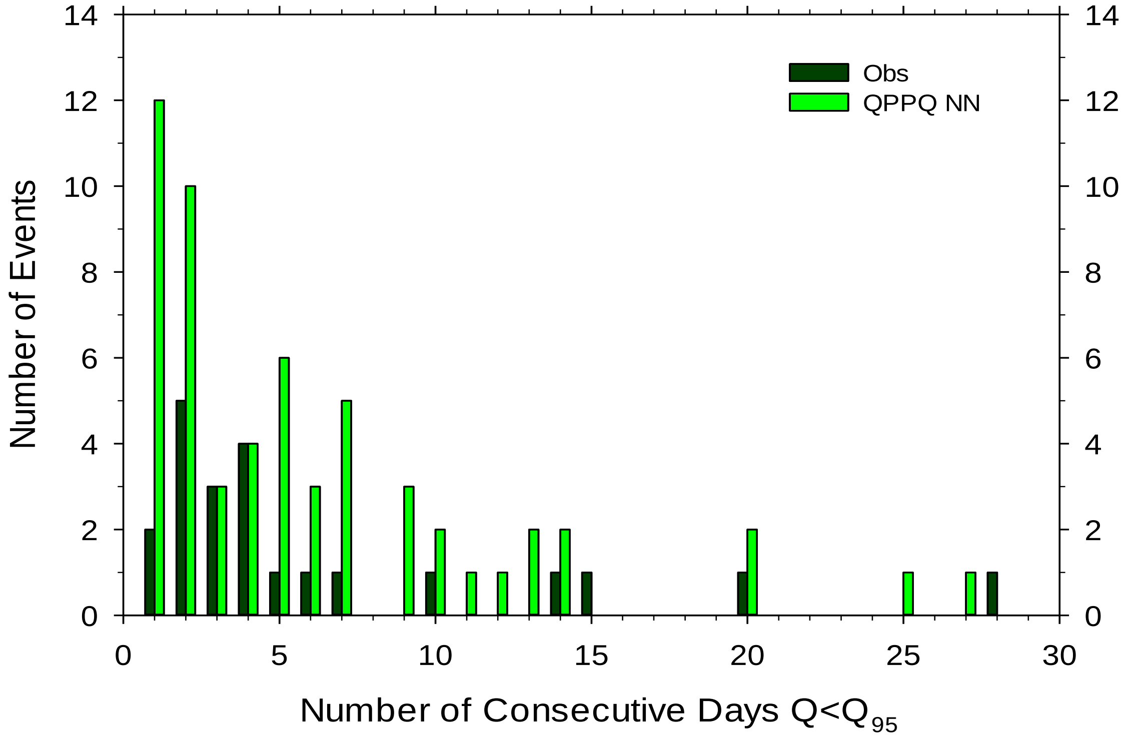


Fig, 4-3a. Cold River Summer Season Frequency of Sub-Q_{85} Event Durations

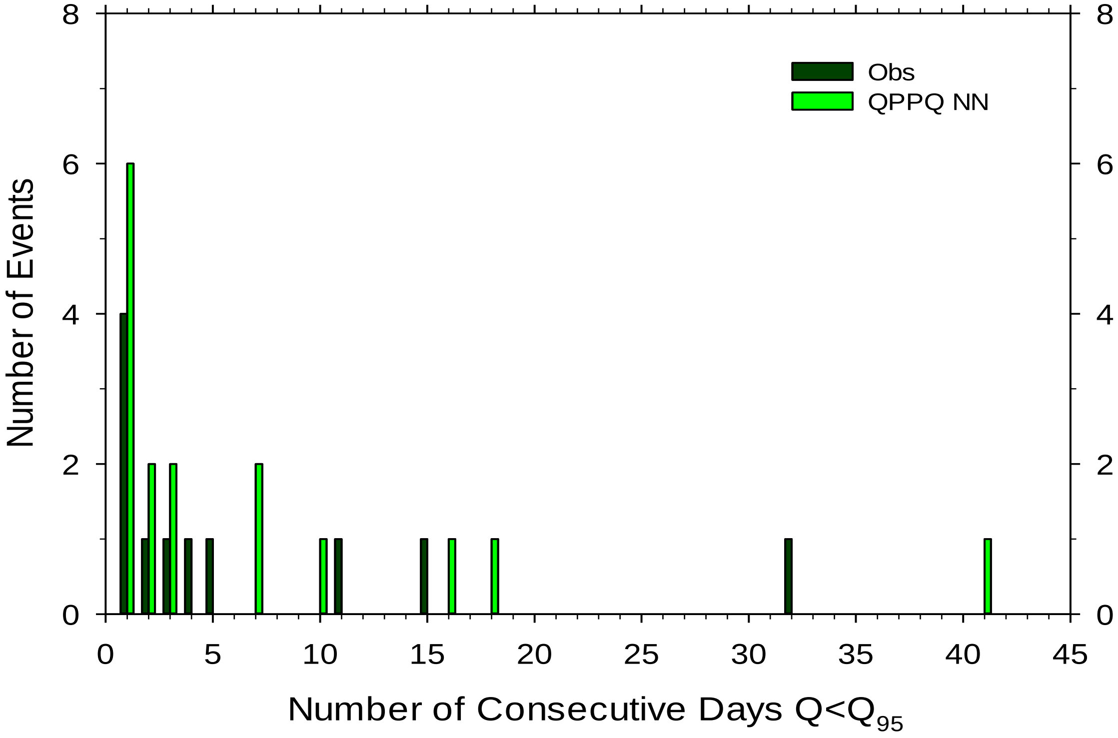


Fig, 4-3b. Warner River Summer Season Frequency of Sub-Q_{85} Event Durations

Figures 4-4a and 4-4b respectively show the sub-Q_{95} threshold negative run-length frequency histograms for the Cold River and the Warner River. For example, Figure 4-4a indicates that there are 2 observed time series negative run-length events that lasted one day but 12 one-day events from the QPPQ Transform time series. Similarly, the longest single observed time series event lasted 28 days, whereas the longest QPPQ Transform time series event lasted 27 days over the concurrent summer season POR. As indicated by Figure 4-4a and confirmed by left side of Figure 4-3b, the difference between the negative run-length characteristics of these two time series results is fairly significant. The degree of frequency cluster similarity between them, as shown by Figure 4-4a, is only fair. However, for event duration 3 or more days, the apparent match is better. Figure 4-4b indicates that there were 4 observed time series negative run-length events that lasted one day and 6 one-day events from the QPPQ Transform time series. Similarly, the longest single observed time series event lasted 32 days, whereas the longest single QPPQ Transform time series negative run-length event lasted 41 days over the concurrent summer season POR. The frequency clustering of both negative run-length histograms is good given the apparent paucity of events over the POR during the summer season.



Fig, 4-4a. Cold River Summer Season Frequency of Sub-Q_{95} Event Durations



Fig, 4-4b. Warner River Summer Season Frequency of Sub-Q_{95} Event Durations

5. Summary and Conclusions

With the assistance of its instream flow advisory committees, NHDES determined that protected instream flows (PIFs) are needed for the development of Instream Flow Rules for two designated watersheds, the Cold River and Warner River watersheds. To assist with that analysis which will begin shortly, HYSR was retained to extend historic streamgage records for a U.S. Geological Survey stream gage located in each watershed. These gage sites are the Cold River at Alstead, NH (01154950) and the Warner River at Davisville, NH (01086000).

The historic record for the Cold River at Alstead is quite short: October 1, 2009 to the present; the Warner River at Davisville was gaged from 1940 to September 30, 1978 and starting again in October 2001 to the present. Using a combination of techniques, the extended daily streamflow time series for each gage site results in a 67-year continuous period-of record beginning October 1, 1950 and ending September 30, 2017. The extended Cold River – Alstead, NH (01154950) gage site time series consists of WAR estimated daily flows (October 1950 – September 1978), QPPQ Transform estimated daily flows (October 1978 – September 2009), and observed daily flows (October 2009 – September 2017). The extended time series for the Warner River at Davisville, NH (01086000) consists of observed daily flows (October 1950 – September 1978), QPPQ Transform estimated daily flows (October 1978 – September 2001), and observed daily flows (October 2001 – September 2017). These two time series were prepared and provided to NHDES in January 2019.

Because both gage sites had periods of historic record, it is possible to determine how well the corresponding QPPQ Transform time series compared with the historic record. In the case of the Cold River, that concurrent POR was October 1950 – September 1978 and October 2009 – September 2017. For the Warner River, the concurrent POR was October 1950 – September 1978 and October 2001 – September 2017. Three types of assessments were performed. Stream flow duration curves (FDCs) were constructed for these concurrent time series for each gage site. The total number of negative run-length periods using a summer season defined as July 1 – September 15 Q_{85} and Q_{95} as thresholds were determined for both the observed and QPPQ Transform estimated concurrent time series at both gage sites. Finally, frequency histograms of the negative run-length event durations using the observed summer season Q_{85} and Q_{95} as thresholds were constructed for both the observed and QPPQ Transform estimated concurrent time series at both the Cold River and the Warner River USGS streamgage sites.

HYSR conducted an assessment of the QPPQ Transform and the observed flows for the most flow-sensitive period of the year from summer to early fall. Between July 15 and September 30, daily stream flows tend to fall within their narrowest and lowest range. The comparative assessment made between concurrent observed summer season daily flows and QPPQ Transform estimated daily flows compare well and the results of three different tests, five all together for each gage site, indicate that these time series are very similar. Particularly, if one considers the minimum negative run-length event duration of concern as being 3 or more days, the results between the two time series is even better. Comparisons between QPPQ Transform and observed flow data during other parts of the year were not made in this study, but are expected to be even more robust. Given these results, HYSR concludes that the QPPQ Transform flow record extensions for the Cold and Warner River gages are very good approximations of the stream flow conditions and are appropriate and suitable for developing stream flow protections on these rivers.

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